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Validating the Commercially Available Garmin Fenix 5x Wrist-Worn Optical Sensor for Aerobic Capacity

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Abstract

Recreational exercisers continue to take a greater interest in monitoring their personal fitness levels. One of the more notable measurements that are monitored and estimated by wrist-worn tracking devices is maximum aerobic capacity (VO2max), which is currently the accepted measure of cardiorespiratory fitness. Traditional methods of obtaining VO2max present expensive barriers, whereas new wearable technology, such as of the Garmin Fenix 5x (GF5) provides a more cost-effective alternative. PURPOSE: To determine the validity of the GF5 VO2max estimation capabilities against the ParvoMedics TrueOne 2400 (PMT) metabolic measurement system in recreational runners. METHODS: Twenty-five recreational runners (17 male and 8 female) ages 18-55 participated in this study. Participants underwent two testing sessions: one consisting of the Bruce Protocol utilizing the PMT, while the other test incorporated the GF5 using the Garmin outdoor protocol. Both testing sessions were conducted within a few days of each other, with a minimum of 24 hours rest between sessions. RESULTS: The mean VO2max values for the PMT trial (49.1 ± 8.4 mL/kg/min) and estimation for the GF5 trial (47 ± 6.0 mL/kg/min) were found to be significantly different ($t = 2.21$, $p = 0.037$). CONCLUSION: The average difference between the GF5 estimation and the PMT was 2.16 ml/kg/min. Therefore, the watch is not as accurate compared to a PMT for obtaining VO2max. However, although not statically significant, the proximity of scores to the PMT shows that the GF5 can be an option for a person seeking an affordable and easily available method of determining VO2max.

Keyword: Garmin Fenix, Optical Sensor

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Abstract

Recreational exercisers continue to take a greater interest in monitoring their personal fitness levels. One of the more notable measurements that are monitored and estimated by wrist-worn tracking devices is maximum aerobic capacity (VO_{2max}), which is currently the accepted measure of cardiorespiratory fitness. Traditional methods of obtaining VO_{2max} present expensive barriers, whereas new wearable technology, such as of the Garmin Fenix 5x (GF5) provides a more cost-effective alternative. ***PURPOSE:*** *To determine the validity of the GF5 VO_{2max} estimation capabilities against the ParvoMedics TrueOne 2400 (PMT) metabolic measurement system in recreational runners.* ***METHODS:*** *Twenty-five recreational runners (17 male and 8 female) ages 18-55 participated in this study. Participants underwent two testing sessions: one consisting of the Bruce Protocol utilizing the PMT, while the other test incorporated the GF5 using the Garmin outdoor protocol. Both testing sessions were conducted within a few days of each other, with a minimum of 24 hours rest between sessions.* ***RESULTS:*** *The mean VO_{2max} values for the PMT trial (49.1 ± 8.4 mL/kg/min) and estimation for the GF5 trial (47 ± 6.0 mL/kg/min) were found to be significantly different ($t = 2.21$, $p = 0.037$).* ***CONCLUSION:*** *The average difference between the GF5 estimation and the PMT was 2.16 ml/kg/min. Therefore, the watch is not as accurate compared to a PMT for obtaining VO_{2max}. However, although not statically significant, the proximity of scores to the PMT shows that the GF5 can be an option for a person seeking an affordable and easily available method of determining VO_{2max}.*

1. Introduction

Throughout the last decade, recreational exercise, particularly running, has been on the rise (Novacheck, 1998; Strohrmann, Rossi, Arnrich, & Troster, 2012), with individuals taking a greater interest in monitoring their personal fitness levels (Leth, Hansen, Nielsen, & Dinesen, 2017). Recent trends have shifted toward an increased use of wrist-worn activity tracking devices that give live feedback of fitness indicators like maximum heart rate (HR_{max}), average heart rate, duration of exercise, and amount of steps taken (Elliot, Hamlin & Lizamore, 2017; Gastin, McLean, Spittle & Breed, 2013; Park & Jayaraman, 2003; Scherr et al., 2009; Winterhalter et al., 2005). Higher quality activity trackers have Global Positioning System (GPS) capabilities that provide detailed information such as distance traveled, pace, elevation, and calories burned during exercise sessions. Most of these devices also double as a casual watch with many other applications and functions that record daily activity. Additionally, the most advanced devices can now estimate maximum aerobic capacity.

Maximum aerobic capacity (VO_{2max}) is frequently monitored by athletes of various levels in order to maximize training and performance (Galy et al., 2003; Malek, Housh, Berger, Coburn, & Beck, 2005; Pollock et al., 1998; Tanaka, Bassett Jr, Swensen & Sampedro, 1993; Whyte et al., 2000). Maximum aerobic capacity is the accepted criterion measure for cardiorespiratory fitness (Jacks, Topp & Moore, 2012; Riebe, Ehrman, Liguori, & Magal, 2018; Washington et al., 1994). The American College of Sports Medicine (ACSM) defines VO_{2max} as the product of maximal cardiac output and maximal arterial-venous oxygen difference (Riebe et al., 2018), which translates to the body's maximal ability to transport and utilize oxygen.

In order to show changes in VO_{2max}, it is imperative to know an individual's baseline VO_{2max} value. Historically this has been performed in a laboratory setting utilizing a metabolic cart, making it difficult for recreational runners to obtain this value. Difficulties include logistics, utilization of gas analysis equipment, and the need for trained technicians (Jacks, Topp & Moore, 2012; Owens & Gutin, 1999; Riebe et al., 2018; Washington et al., 1994). Accessibility to facilities is also a negative factor when comparing the PMT to the GF5, due to the burden of coordinating with a university or private organization to conduct a VO_{2max} test (Jacks, Topp & Moore, 2012; Owens & Gutin, 1999; Washington et al., 1994). Most facilities are often unavailable to the public, which creates an increased demand for other measurement techniques. Furthermore, there is a large price difference between a PMT and the GF5. The current price for the GF5 is $650 according to the company's website (Garmin.com), which is considerably cheaper than a PMT system which cost approximately $20,000 (Kraft & Dow, 2018).

Metabolic carts are considered valid for measuring VO_{2max} due to their ability to measure expired gases with very high rates of accuracy and reliability (American Thoracic Society, 2003; Franklin, Whaley, Howley, & Balady, 2000; Malek, Housh, Berger, Coburn, & Beck, 2005; Riebe et al., 2018). Another method of measuring VO_{2max} by gas analysis is the use of a portable metabolic system. Portable metabolic systems can be used during field testing to obtain aerobic capacity (VO_2) values. However, previous studies have shown these portable metabolic units to underestimate VO_2 at rest and overestimate VO_2 at all work rates (Crouter, Antezak, Hudak, DellaValle, & Haas 2006; Díaz, 2008; Perret & Mueller, 2006). Due to these discrepancies, portable metabolic units may not be a reliable means of obtaining VO_{2max}.

Over the past few decades, recent advancements in wearable technology have made this monitoring increasingly accessible and affordable when compared to traditional laboratory methods (de Zambotti et al., 2016; Evenson, Goto, & Furberg, 2015; Kolla, Mansukhani, & Mansukhani, 2016; Lee & Finkelstein, 2015). Currently, Garmin is one of the leading commercial providers of high-quality fitness trackers. One of their most recent products is the Garmin Fenix 5x (GF5). The GF5 are designed with an optical sensor to measure HR, which allows the user to forego using a HR strap. They are worn on the individual's wrist, which makes them considerably more portable when compared to the larger portable metabolic systems, which require the user to wear a facemask and a small pack with tubing connecting the two components. The GF5 uses GPS and its optical sensor to estimate an individual's VO_{2max} while running for at least 10 minutes outdoors (Garmin Fenix 5x owner's manual, 2017, p. 8-9). In order to calculate ones estimated VO_{2max}, the GF5 uses an algorithm developed by Firstbeat Technologies and is estimated to have an error range of 3.5 ml/kg/min (Firstbeat Technologies, 2017, p. 4). When compared to the portable metabolic systems, the GF5 is less bulky, user-friendly, and requires no training. However, even with the expanding availability of wrist-worn fitness tracking devices, the validity of these devices still remain in question.

Therefore, the purpose of this study was to determine the validity of the GF5 VO_{2max} measurement capabilities against the PMT in recreational runners. It was hypothesized that the VO_{2max} measurements obtained from the GF5 when performing the recommended Garmin maximal aerobic capacity testing protocol would be within 3.5 mL/kg/min between those VO_{2max} values obtained from the PMT open circuit spirometry when utilizing the Bruce treadmill protocol.

2. Discussion

The purpose of this study was to examine the accuracy of the GF5 in measuring VO_{2max} in recreational runners when compared against PMT. After analyzing the data collected, the hypothesis for the VO_{2max} measurements of the GF5 and the PMT being within 3.5 ml/kg/min was accepted. On average, the GF5 results underestimated VO_{2max} by 2.16 ml/kg/min and was within the manufacturers estimated error range of 3.5 ml/kg/min (Firstbeat Technologies, 2017, p. 4). This supports the company's claims and reinforces the GF5s ability to estimate aerobic exercise capacity.

In two previous studies, both using wrist-based fitness trackers paired with a HR strap, VO_{2max} was validated against the PMT system. One study conducted by Kraft and Roberts (2017) utilized the Garmin Forerunner 920XT (GF920) with a HR strap and validated its ability to measure VO_{2max}, using the Garmin 10 minute outdoor test, against the PMT. Kraft and Roberts (2017) found the GF920 was not significantly different from the PMT ($t = 0.221$, $p = 0.828$), with a mean VO_{2max} difference of only 0.25 mL/kg/min. A study by Kraft and Dow (2018), validated the Polar RS300x (P300) with a HR strap, using the Polar fitness test, which requires an individual to lay down for 5 minutes, against the PMT system. Kraft and Dow (2018) found there was no significant difference between the P300 and PMT ($t = 1.681$, $p = 0.111$), and that there was a mean VO_{2max} difference of 3.58 mL/kg/min. Even though the GF5 was found to be significantly different, the mean difference of the GF5 (2.16 ml/kg/min) was within the range of the GF920 (0.25 mL/kg/min) and P300 (3.58 mL/kg/min) fitness trackers. A key difference between the GF5 and the other two sensors was that the GF5 underestimated VO_{2max} while the other two overestimated VO_{2max}.

Unlike these two previous studies, the GF5 only uses an optical sensor to measure HR, and that value is used to estimate VO_{2max}. Thus, this may contribute to why the GF5 underestimated VO_{2max}. Currently the more advanced wrist-worn fitness trackers like the GF5 are designed to learn and analyze biometric data such as HR average and max, HR variability, and stress level over an extended period of time and build a user profile (Altini, Penders, & Amft, 2016; Beltrame, Amelard, Wong, & Hughson, 2017; Firstbeat Technologies, 2014; Mannini & Sabatini, 2010; Witten, Frank, Hall, & Pal, 2016). Due to the GF5 only being used for 10 minutes, there may not have been enough time to acquire sufficient biometric data to establish an accurate VO_{2max}. Therefore, the GF5's ability to learn and analyze data over time may be the most significant reason as to why the GF5 underestimated VO_{2max}. Due to this negligible difference, the GF5 is a cost-effective means to obtaining an individual's VO_{2max}.

Given the GF5's ability to estimate VO_{2max} with an under estimation of 2.16 ml/kg/min, individuals can design and implement a training regimen to improve their aerobic performance. Knowing this margin of VO_{2max} error, trainers and athletes can sustain longer and safer training programs without the negative side effects of overtraining (Firstbeat Technologies, 2015). Due to the cost of the GF5, not everyone will be able to afford this training tool, but trainers and clinicians could still conduct field tests periodically to assess their client's aerobic fitness. Additionally, physicians and/or clinicians could use the GF5 as a take home piece of exercise equipment to determine the level of fitness of their patients/clients. It could also be used to help patients/clients stay within a safe level of exercise intensity.

Possible limitations of this study included wrist placement of the GF5 with each participant, self-perceived exertion level of each participant completing the Garmin outdoor run, and only conducting one outdoor run with the watch. The GF5 manual recommends watch placement above the styloid processes of the radius and ulna. During some testing, there was potential for the watch to slide down a participant's wrist due to wrist diameter and size limitations of the watch strap. Garmin states that a runner can obtain their VO_{2max} estimation with as little as one 10-minute run outdoors, and the measurements become more accurate the more one trains with the GF5. Due to only running once outdoors, the GF5 may not have recorded the most accurate VO_{2max} estimation.

Future studies could address the previous limitations as well as observe the difference between the wrist-worn optical sensor and a Garmin heart rate strap in consideration to VO_{2max}. Furthermore, future studies could examine the accuracy between the Garmin outdoor run and a speed based treadmill protocol, which more accurately replicates the running mechanics of the flat outdoor test as opposed to the increased grade of the Bruce protocol.

3. Conclusion

With a mean VO_{2max} difference of only 2.16 ml/kg/min, the GF5 is a viable option to provide an accurate, cheaper, and more accessible means of obtaining VO_{2max} in recreational runners. One of the major factors individuals must determine is if a difference of 2.16 ml/kg/min is negligible enough to develop, monitor, and adjust training programs as needed. An additional benefit of the GF5 is that it only utilizes a wrist-worn optical sensor and requires no additional components like a HR strap. The GF5 is also a more cost-effective option to measure VO_{2max} for personal use or for an organization's personnel than the PMT, which would require an individual to schedule an appointment with a university or health and wellness center. Due to these advantages recreational and professional athletes, first responders, and military will be able to monitor and improve their cardiorespiratory fitness with a wrist-worn optical sensor.

4. Acknowledgments

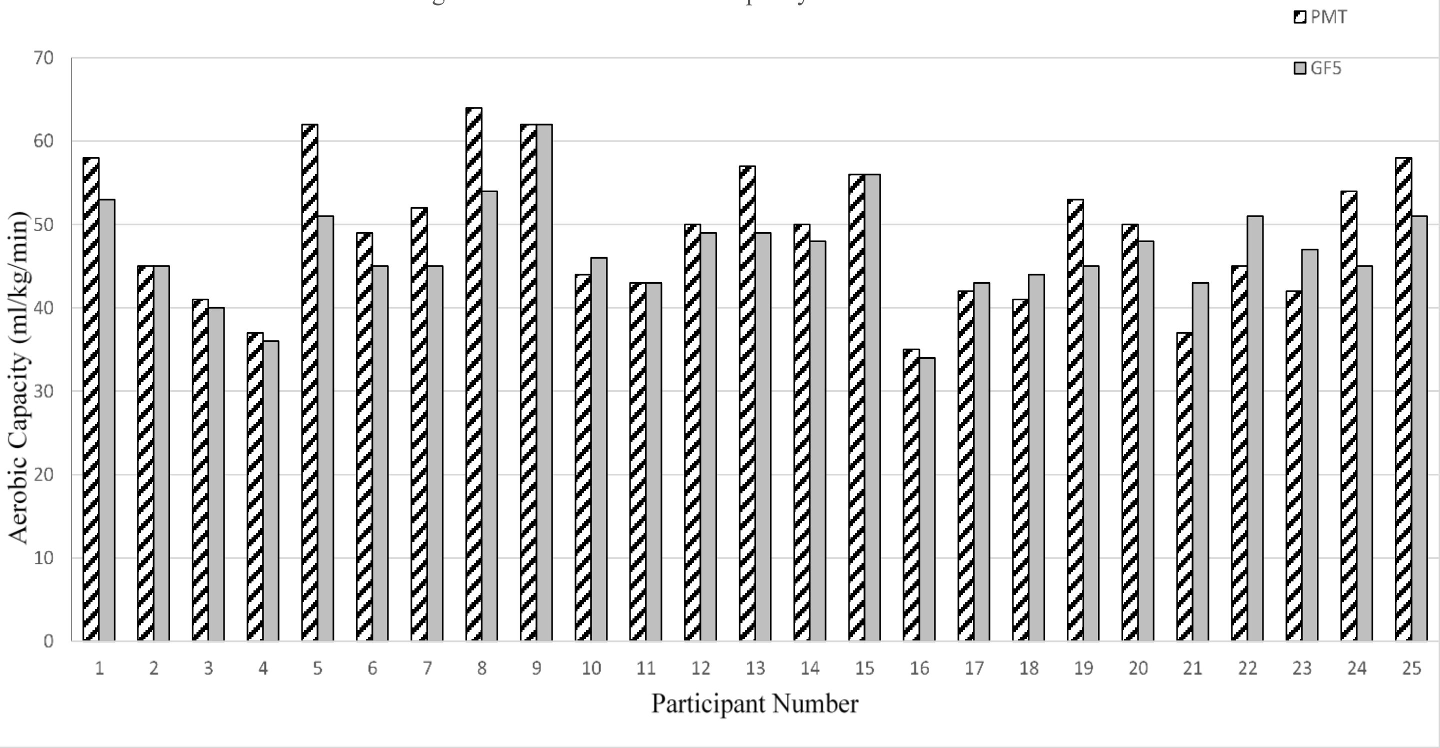
The researchers would like to thank all of the participants for all of their time and help.

Table 1. Participant Characteristics

Variables	M ± SD
Age (years)	39.4 ± 10.8
Height (cm)	173.9 ± 9.9
Weight (kg)	73.9 ± 11.2
PMT $VO2_{max}$ (ml/kg/min)	49.1 ± 8.4
GF5 $VO2_{max}$ (ml/kg/min)	47.0 ± 6.0
PMT $VO2_{max}$ – GF5 $VO2_{max}$ (ml/kg/min)	2.16

Note. M = mean, SD = Standard Deviation, PMT = ParvoMedics TrueOne 2400, GF5 = Garmin Fenix 5x, $VO2_{max}$ = Maximal Aerobic Capacity. Participants consisted of 17 males and 8 females.

Figure 1. Individual Aerobic Capacity Performance Values



Note. All aerobic capacity values are displayed as mean scores (ml/kg/min) for each trial; PMT = ParvoMedics TrueOne 2400, GF5 = Garmin Fenix 5x; The overall average for PMT = 49 ml/kg/min and for GF5 = 47 ml/kg/min.

5. Methodology

5.1 *Participants*

Individuals were recruited from a university community and its surrounding area through local contacts with running organizations. Twenty-five recreational runners (17 male and 8 female) ages 18-55 were recruited to participate in this study (Table 1).

Table 1. Participant Characteristics

Variables	M ± SD
Age (years)	39.4 ± 10.8
Height (cm)	173.9 ± 9.9
Weight (kg)	73.9 ± 11.2
PMT $VO2_{max}$ (ml/kg/min)	49.1 ± 8.4
GF5 $VO2_{max}$ (ml/kg/min)	47.0 ± 6.0

PMT $VO2_{max}$ - GF5 $VO2_{max}$ (ml/kg/min)	2.16

Note. M = mean, SD = Standard Deviation, PMT = ParvoMedics TrueOne 2400, GF5 = Garmin Fenix 5x, $VO2_{max}$ = Maximal Aerobic Capacity. Participants consisted of 17 males and 8 females.

Recreational runners were categorized as those individuals who run at least 2 hours/week for a minimum of 12 months (Demers, Heest, Lasley, & de Souza, 2003). Prior to involvement in the study, all participants completed an informed consent and The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) form, each approved by the university IRB. The exclusion criteria consisted of whether or not a participant had sustained a lower-body injury within the last six months, was currently taking any supplementation (over the counter or prescription) that would alter maximum cardiovascular performance, or had been diagnosed by a physician with cardiovascular, pulmonary, or metabolic disease.

5.2 Instrumentation

1.2.1 Criterion Device.

The PMT (Sandy, Utah, United States) was powered on with a minimum of 30 minutes prior to calibration (Macfarlane and Wu, 2013). The PMT was calibrated according to the manufacturer's guidelines, which consisted of conducting a room air auto-calibration protocol with a two-point gas calibration protocol using a single gas tank, and flow meter calibration prior to each testing session (Crouter et al., 2006).

2.2.2 Comparison Device.

The GF5 (Canton of Schaffhausen, Switzerland) was calibrated using each participant's height, mass, gender, and birth year. To ensure device reliability, only one GF5 was used during the entire study.

2.2.3 Outcome Measures

Participants were advised to refrain from consuming caffeine on the day of testing and abstained from lower body exercise 48 hours prior to testing. Session 1 was conducted in a University exercise physiology lab. When participants arrived, height (Seca 217 stadiometer, Hanover, MD, United States), weight (Seca 869 scale , Hanover, MD, United States), and age-predicted maximum heart rate (220 – age) were recorded for each individual. Demographic data from each participant were entered into the PMT. Also, the proper fitting of a Hans Rudolph face mask (Shawnee, Kansas, United States) and Polar heart rate monitor (Bethpage, New York, United States) was performed prior to the Bruce protocol test. During the Bruce protocol, participants were monitored for signs and symptoms to terminate testing, according to the following criteria outlined by the ACSM: (1) Respiratory exchange ratio (RER) greater than or equal to 1.10, (2) Failure of HR to increase with increases in workload, (3) Rating of perceived exertion > 17 on the 6-20 scale, (4) Lactate concentration > 8.0 mmol per liter, (Balady et al., 2010; Morris et al., 1993; Riebe et al., 2018; Taylor, Buskirk, & Henschel, 1955). All participants conducted a true max test and met at least two of the criteria. Additionally, all tests involved the participants achieving a plateau in VO_{2max}, which was defined as an increase of less than 2 ml/kg/min with an increase in exercise intensity. Maximal heart rate (HR_{max}) and VO_{2max} were both measured during the Bruce protocol. Participants were observed for 5 minutes following proper cool down to ensure safety.

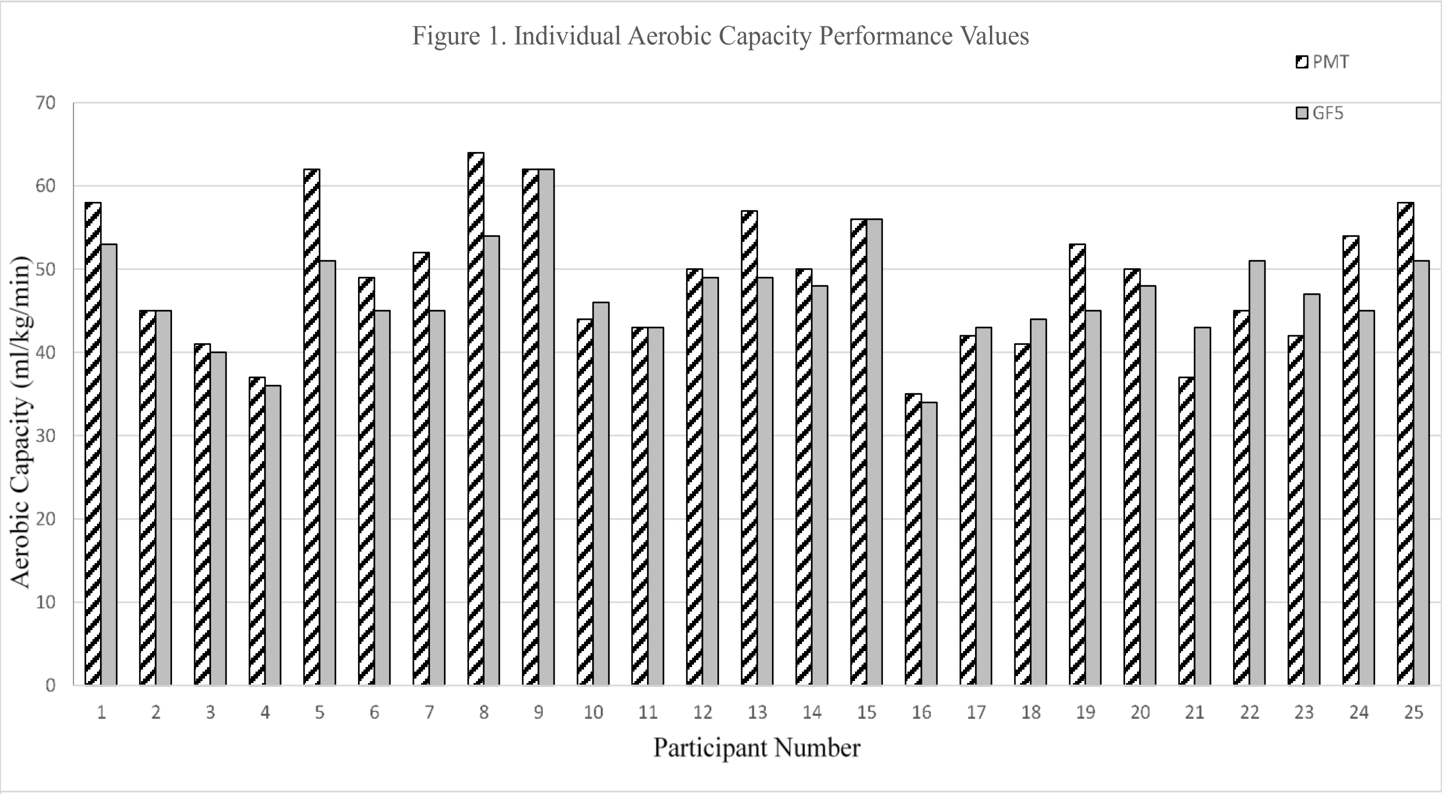
Session 2 was conducted at a local high school track within a few days after session 1 with a minimum of 24 hours' rest. The participants were also asked to refrain from caffeine intake and exercise participation prior to session 2. The second session was conducted outside during the same time of the day as session one to reduce any circadian differences in heart rate. Prior to participant arrival, the GF5's GPS was initiated in order to acquire a satellite signal, which is required to estimate VO_{2max}. Participant's height, weight, gender, and age were entered into the GF5 for an accurate VO_{2max} estimation, and the device was fixed to their left wrist for consistency. Participants were then instructed to walk or jog for at least two laps in the first lane of the track as a warmup before testing began. For testing, participants ran at their highest perceivable pace for a 10-minute duration. The Garmin VO_{2max} protocol only requires an individual to run a minimum of 10 minutes outdoors to obtain a VO_{2max} estimation. After completing their run, the participants conducted a cool down session that consisted of walking 2 laps at a self-selected pace, and their heart rates were observed for 5 minutes to ensure safety. The GF5 was then removed from the participant, and their VO_{2max} recorded.

2.3 Statistical Analyses

Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) version 24.0. Paired sample *t*-tests were used to compare VO_{2max} values between the two testing sessions. Statistical significance was established at $p < 0.05$. To determine the level of strength between the PMT and GF5, a Pearson correlation coefficient was administered VO_{2max}.

6. Results

The average PMT VO_{2max} was 49.1 ± 8.4 mL/kg/min, while the average VO_{2max} for the GF5 was 47.0 ± 6.0 mL/kg/min. The VO_{2max} was significantly different between the test performed on the PMT compared to the estimation provided by the GF5 ($t = 2.21$, $p = 0.037$). For VO_{2max}, there was a statistically significant positive correlation between the PMT and GF5 ($r = 0.819$, $p < .001$). All testing values are displayed in Figure 1.



Note. All aerobic capacity values are displayed as mean scores (ml/kg/min) for each trial; PMT = ParvoMedics TrueOne 2400, GF5 = Garmin Fenix 5x; The overall average for PMT = 49 ml/kg/min and for GF5 = 47 ml/kg/min.

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